

Production of a Fermentation Product

The present invention relates to processes of treating a substrate, and in particular plant derived material, to provide an aqueous liquor containing sugars
5 which are used in a fermentation process to produce a fermentation product. In particular the present invention relates to a process of dewatering a fermentation broth residue, produced as a by-product from the distillation recovery of a fermentation product or dewatering a fermentation broth to remove solids prior to carrying out a distillation recovery of a fermentation
10 product. Typically the dewatered solids are dried and used as a solid fuel. The clarified water would normally be returned to watercourses and/or used as wash liquor further back in the process.

Typically such fermentation products include for instance ethanol, glycerol,
15 acetone, n-butanol, butanediol, isopropanol, butyric acid, methane, citric acid, fumaric acid, lactic acid, propionic acid, succinic acid, itaconic acid, acetic acid, acetaldehyde and 3-hydroxypropionic acid, glyconic acid and tartaric acid and amino acids such as L-glutamic acid, L-lysine, and L-aspartic acid, L-tryptophan, L-arylglycines or salts of any of these acids.

20 It is known to treat a biomass with acid in order to hydrolyse polysaccharides to the component sugars that can be used in a fermentation process to produce a fermentation product. For instance US-A-4384897 describes a method of treating biomass material in which it is subjected to a two stage hydrolysis in
25 which polysaccharides that are more easily hydrolysed, such as hemicellulose and then in a second stage the material that is more difficult to depolymerise e.g. cellulose, is depolymerised using a more severe hydrolytic treatment. The products of the first and second stages include sugar solutions, organic acids and aldehydes. The monosaccharides are subjected to fermentation to produce
30 ethanol and the beer resulting from the fermentation may then be subjected to rectification to produce ethanol of commercial grade. US-A-4384897 sets out to

provide improvements in more efficient washing of solids, the use of co-current washing or countercurrent washing of solids and proposes the use of ferric and or aluminium ions as flocculating agents to separate finely dispersed solids resulting from the neutralisation of the hydrolysate liquor stream.

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US 4,728,613 describes the use of a glycol derivative and an inorganic salt to recover extracellular enzymes from whole fermentation beer. High concentrations of the glycol derivative (1-15 weight percent) and inorganic salt (8-35 weight percent) are used to form a 2 phase system to recover the enzyme.

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US 5,552, 316 concerns the combination of anionic and cationic flocculants that are used to clarify an aqueous solution containing microbial cells (*Escherichia coli*). The *E. coli* is generated in a fermentation process.

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It is also known from a National Renewable Energy Laboratory (NREL) report entitled "Lignocellulose Biomass to Ethanol Process Design and Economics of Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis Current and Future Scenarios", NREL/IP-580-26157 (July 1999) to treat cellulose as the second polysaccharide by a cellulase enzyme in order to hydrolyse the cellulose into its component sugars. In one form of this process the solid by-product residue resulting from the first hydrolysis step and containing cellulose is divided into a main stream and a secondary stream. The main stream is fed directly into the fermentation vessel and the secondary stream is passed to a cellulase production stage, in which fungi are allowed to grow and act upon the cellulose, such that sugars and cellulase are formed. The sugars and cellulase are then fed into the fermentation vessel and the cellulase acts upon the cellulose from the main stream and converts it into the component sugars which in turn can be fermented to produce the fermentation product.

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It is known to treat shredded cellulosic material using concentrated acid to

provide aqueous solutions of sugars, which can be used in a fermentation process. For instance US-A-4650689 discloses a process of preparing ethanol from cellulosic material by subjecting the cellulosic material to highly concentrated mineral acid gas such as HCl under pressure, and treatment with
5 hot water to give a liquor containing sugars which can be fermented.

US-A-5975439 describes an automated process for producing ethanol by shredding the cellulosic component of municipal solid waste and mixing this with equal amounts of concentrated sulphuric acid at high temperature to provide a
10 digested mixture. The aqueous sugar solution is separated from the solids by a filtration process before being subjected to a fermentation process.

However, in the recovery of the fermentation product from the fermentation broth it is sometimes necessary to continually distil off the fermentation product
15 in a distillation stage, wherein a stillage stream, comprising residues and by-products is removed.

WO-A-8603514 describes manufacture of ethanol by fermentation and then extraction of the ethanol from the fermentation broth. The residual fermentation
20 broth liquor contains yeast and dissolved polymeric materials such as polysaccharides and proteins. An advantage of locating the solid liquid separation stage after the distillation stage is that some part of the non-separable dissolved protein in the fermentation liquor is transferred into a separable form through coagulation due to heating in the distillation and heat
25 exchange processes.

In a study by Ann C Wilkie *et al.*, (Biomass and Bioenergy 19 (2000) 63-102), the treatment of ethanol stillage is evaluated. The bacterium, *Zymomonas mobilis* has been shown to produce higher ethanol yields but there is difficulty in
30 separating the stillage liquor from the solid material. The study also identifies

the difficulty in separating suspended solids from sugar crops and cellulosic crops.

In general, the stillage stream or still bottoms resulting from the distillation processes is subjected to solids-liquid separation step to produce a dewatered product which can be dried to produce a dry solid fuel product. The aqueous liquid separated from the solids are either returned to watercourses and/or recycled as wash water used in the washing of acid treated plant derived material. The stillage stream or still bottoms are normally high in biological oxygen demand (BOD) and so it is important to ensure that the aqueous liquid is effectively clarified and the water produced there from is substantially free of impurities in order not to poison watercourses and/or when used as wash liquor contaminate the substrate that is being washed.

The stillage stream contains precipitated protein based impurities and high levels of lignin, which make it difficult to flocculate and effect solids liquid separation. It is known from an NREL report entitled "Liquid/Solid Separation" 99-10600/14 (March 2001) to treat post distillate slurry with a single polymer solution of concentration 0.01 to 0.02 wt%, identified as Perc-765, at doses in the range of 0.4 to 1 kg/tonne of dry solids to effect the dewatering of the solids on a belt press to a final solids content of 26-29 wt%. However, the filtrate clarity is poor. When separating a dilute feed of 3 to 4 wt% insolubles a filtrate containing solids of 0.25 wt% or greater is produced. It is noted that when operating with a desired feed concentration of 11.7 wt%, the ability to flocculate the solids may be even worse and it will be necessary to either dilute the feed stream, use greater mixing intensity, and/or increase the polymer dose. Based on the final solids content and the filtrate solids achieved in these studies belt presses were not recommended for this application. Normally such liquors have been subjected to elevated temperatures, for instance above 50°C and can be as high as 95°C or 100°C and for process time and energy efficiency reasons

may require solid/liquid separation at elevated temperatures, typically above 50°C which adds further to the difficulty of optimisation of the separation stage.

International application PCT/ EP 03/08427 (unpublished at the priority date of the present application) addressed the difficulty in adequately flocculating such liquors that have been subjected to these elevated temperatures.

Improvements in solid/liquid separation of a fermentation product that comprises lignin were achieved using a treatment system comprising a cationic polymer having an intrinsic viscosity of at least 4 dl/g. The process involves using a dose and of cationic polymer of above 2 kg/tonne based on dry weight of suspension, or in using the cationic polymer and a co-additive selected from an anionic polymer, a cationic polymer of intrinsic viscosity below 4 dl/g and a cationic charge density of at least 3 meq/g and/or inorganic coagulants and/or charged microparticulate material.

The term "fermentation liquor" is used here to include mixtures often referred to as "mixed fermentation liquor", or "fermentation broth". These liquors include those resulting from agricultural plant derived materials that have been subjected to one or more fermentation stages.

We provide a process of separating suspended solids from a fermentation liquor by subjecting the liquor to a solids liquid separation stage, wherein the fermentation liquor is produced in a fermentation process for the production of a fermentation product and in which the liquor comprises lignin, wherein the solids liquid separation stage is assisted by a treatment system, characterised in that the treatment system comprises an anionic polymer, with the proviso that the treatment system does not include a cationic polymer having an intrinsic viscosity (IV) of at least 4 dl/g.

We have found that surprisingly the yield and/or efficiency of the process can be improved by effecting a rapid but efficient solids liquid separation of the solid

residues from an aqueous fermentation liquor containing lignin and other lingo-cellulosic type materials and that the liquor can be recycled to the fermentation process. Generally the fermentation liquor will also contain BOD. The treatment system of the present invention allows a significantly improved separation of
5 liquors from the solid residues and by-products. In particular the process induces more effective flocculation and the separation process is found to be significantly faster. In addition the solid residues, which contain mainly lignin, resulting from the separation process have higher cake solids than conventional separations. Such a solid product would take less time and energy to dry and
10 thus can be for instance used more efficiently as a solid fuel.

The aqueous fermentation liquor that contains biomass, lignin and other solid matter(that has undergone fermentation) may have been subjected to elevated temperatures through the inclusion of a heat treatment step. Such heat
15 treatment may result in temperatures of at least 50°C or significantly above, for instance 60 or 70°C and especially in the range of 80 to 100°C. In one aspect of the invention the process is particularly suitable to separation processes in which the fermentation liquor has been subjected to a distillation step. The process enables the recovery of soluble components from distillation still bottom
20 liquors (stillage) that are produced as a result of fermentation and that are rendered insoluble through distillation of the fermentation liquor in the production of a fermentation product, for instance ethanol. In another aspect of the invention the aqueous fermentation liquor may not have been subjected to an elevated temperature. This may for instance be in an analogous process in
25 which the lignin containing solids are separated from the aqueous fermentation liquor in a solids liquid separation step before carrying out the distillation in a subsequent recovery of the fermentation product.

Thus we also provide a process of separating suspended solids from a
30 fermentation liquor by subjecting the fermentation liquor to a solid-liquid separation stage,

wherein the fermentation liquor is produced in a fermentation process for the production of a fermentation product,
which fermentation liquor comprises lignin and in which the fermentation liquor has not been subjected to a temperature of at least 50°C,
5 wherein the solids-liquid separation stage is assisted by a treatment system, characterised in that the treatment system comprises an anionic polymer.

Generally the fermentation liquor (containing biomass) will tend to be at a pH below neutral and often below 6. The pH can be as low as 3 but it usually
10 would be at least 4 or 5.

The process concerns the dewatering of lignin-containing fermentation liquor and separation of solids therefrom, in which the fermentation liquor may or may not have been heat-treated. Typically the fermentation liquor may be derived
15 from material such as lignocellulosics.

The process is particularly suitable for liquors containing lignin and which are high in BOD caused by the presence of soluble organic compounds and in which the recovered clarified aqueous stream can be recycled into an earlier
20 stage of the process. The treatment system of the present invention enables a significantly improved separation of liquid from the solid residues and by-products. In particular the process induces more effective flocculation and the separation process is found to be significantly faster. In addition when the fermentation liquor contains lignin the solid residues (mainly lignin), resulting
25 from the separation process have higher cake solids than those recovered from conventional separations. Such a solid product would take less time and energy to dry and thus can be for instance used more efficiently as a solid fuel.

In one aspect of the present invention the fermentation liquor is subjected to a
30 distillation stage in which the fermentation product is recovered, wherein the fermentation liquor is removed from the distillation stage as a stillage stream

and then subjected to the solids liquid separation stage. Thus in this form of the invention the fermentation liquor is essentially free of the fermentation product when it is subjected to the solids liquid separation stage.

- 5 Alternatively the fermentation liquor contains the fermentation product wherein the fermentation liquor is subjected to the solids liquid separation stage and then passed to a distillation stage wherein the fermentation product is recovered. Thus in this form of the invention the solids are removed prior to the distillation stage and thus the distillation column and the stillage stream
10 produced there from will be substantially free of the solids.

The anionic polymer may be a suitable anionic natural, modified natural (semi-natural) or synthetic polymer. We have found that the treatment system is particularly effective when using polymers that have a high anionic charge. The
15 natural polymer will preferably have a low equivalent weight below 300 (generally this is higher than 3.3 meq/g) and more preferably below 240 or 230. The equivalent weight can be as low as 150 or lower. The equivalent weight is the molecular weight divided by the number of anionic charges per polymer molecule. This can be determined by colloid titration. Preferably the synthetic
20 anionic polymer used in the treatment system will comprise above 50% by weight anionic monomer units, (generally this is greater than 5.3 meq/g), especially above 60%, suitably between 65 and 100% by weight. In some cases it may be particularly desirable to use polymers that comprise an at least 70 or at least 80% by weight anionic monomer.

25 The anionic polymer may be a synthetic, modified natural (semi-natural) or natural polymer. Examples of suitable natural polymers include sulphated polysaccharides such as carrageenan. Other suitable polysaccharides include those containing uronic acids such as alginates and pectins.

Synthetic anionic polymers may be derived from ethylenically unsaturated monomer or monomer blend comprising at least one anionic monomer. Typically the anionic monomer and can be any suitable water-soluble ethylenically unsaturated monomer and containing a pendant acid group
5 existing either as the free acid or a salt thereof. The anionic polymer may be formed from anionic monomers selected from the group consisting of (meth) acrylic acid (or salts), maleic acid (or salts), itaconic acid (or salts), fumaric acid (or salts), vinyl sulfonic acid (or salts), allyl sulfonic acid and 2-acrylamido-2-methyl sulfonic acid (or salts). Suitable salts of the anionic monomers include
10 alkali metal and ammonium salts. The polymers may be formed by the polymerisation of at least one anionic monomer optionally in the presence of other suitable monomers, which could for instance be water-soluble non-ionic monomers such as acrylamide. By water-soluble we mean that the monomer has a solubility of at least 5g/100 ml at 25°C. A particularly suitable polymer is
15 sodium acrylate and its copolymer of sodium acrylate with acrylamide.

The polymers may be linear in that they have been prepared substantially in the absence of branching or cross-linking agent. Alternatively the polymers can be branched or cross-linked, for example as in EP-A-202780. In the invention the
20 anionic polymer may be formed by any suitable polymerisation process. The polymers may be prepared for instance as gel polymers by solution polymerisation, water-in-oil suspension polymerisation or by water-in-oil emulsion polymerisation. When preparing gel polymers by solution polymerisation the initiators are generally introduced into the monomer solution
25 to initiate polymerisation. Once the polymerisation is complete and the polymer gel has been allowed to cool sufficiently the gel can be processed in a standard way by first comminuting the gel into smaller pieces, drying to the substantially dehydrated polymer followed by grinding to a powder. The polymers may be produced as beads by suspension polymerisation or as a water-in-oil emulsion
30 or dispersion by water-in-oil emulsion polymerisation, for example according to a process defined by EP-A-150933, EP-A-102760 or EP-A126528.

The anionic polymer is typically a high molecular weight polymer having a molecular weight above 500,000 and usually of several million, for instance 5 to 30 million. Preferably the anionic polymer exhibits an intrinsic viscosity of at least 4 dl/g. An aqueous polymer solution (0.5-1% w/w) is prepared based on the active content of the polymer. 2 g of this 0.5-1% polymer solution is diluted to 100 ml in a volumetric flask with 50 ml of 2M sodium chloride solution that is buffered to pH 7.0 (using 1.56 g sodium dihydrogen phosphate and 32.26 g disodium hydrogen phosphate per litre of deionised water) and the whole is diluted to the 100 ml mark with deionised water. The intrinsic viscosity is measured using a Number 1 suspended level viscometer at 25°C using the buffered salt solution as a 'blank' reading.

Particularly preferred polymers exhibit an intrinsic viscosity from 6 or 7 dl/g and can be as high as 20 or 30 dl/g or higher. Typically they can be in the range of 11 or 12 up to 26 or 27 dl/g.

The dose of anionic polymer is typically at least 50 grams per tonne (based on dry weight of fermentation liquor). The dose is usually significantly higher, and can be typically up to 5000 grams per tonne. Usually the amount of polymer is added in an amount between 500 and 3000 grams per tonne, especially around 750 to 2000 grams per tonne.

The treatment system desirably may employ the anionic polymer as a sole treatment agent. On the other hand for some systems it may be appropriate to use an additional flocculating agent or coagulant. The additional flocculating agent or coagulant may be for instance polymeric or non polymeric and it could be organic or inorganic. However, the additional ingredient should not include a cationic polymer having an intrinsic viscosity (IV) of at least 4 dl/g. We have found that the separation process is particularly effective when the treatment system comprises a cationic coagulant as a second component in addition to

the anionic polymer. In particular a preferred embodiment employs a treatment system that comprises (i) the anionic polymer and (ii) a cationic polymer of intrinsic viscosity of below 4 dl/g.

- 5 In a treatment system comprising anionic polymer and cationic polymer of intrinsic viscosity below 4 dl/g, these may be added simultaneously, either as a pre-mix or alternatively separately. In one preferred form of the invention the anionic polymer is added first followed by the addition of low IV cationic polymer. The reverse order of addition is also possible and may be particularly
10 suited to certain cases.

The cationic polymer may be a low IV natural, semi-natural or synthetic cationic polymer which exhibit intrinsic viscosity of below 4 dl/g and a cationic charge density of at least 3 meq/g.

- 15 Preferably the low IV polymer is selected from the group consisting of polyamines, amine/epihalohydrin addition polymers, polymers of dicyandiamide with formaldehyde, polymers of diallyldimethyl ammonium chloride (DADMAC), cationic starch, cationic inulin, polymers of dialkyl amino alkyl (meth) acrylates
20 (or salts) and dialkyl amino alkyl (meth) acrylamides (or salts). Polyamines may be commercially available polyamines, for instance polyethyleneimine (PEI). Cationic starch or cationic inulin may be commercially available products.

- Preferred cationic polymers are addition polymers of formaldehyde with
25 dimethylamine and optionally other amines such as ethylenediamine or polymers of formaldehyde with dicyandiamide. More preferred low IV polymeric coagulants include polymers of water soluble ethylenically unsaturated cationic monomer or blend of monomers of at least one cationic, non-ionic and/or anionic monomer(s) alone or with other water soluble monomers, provided that
30 the polymer has a cationicity of at least 3 meq/g. By water-soluble we mean that the monomer has a solubility of at least 5g/100 ml at 25°C. Particularly preferred

polymers are homopolymers of diallyldimethyl ammonium chloride or copolymers of diallyldimethylammonium chloride with up to 20 mole% acrylamide. Typically such polymers would have molecular weights of up to 2,000,000 and usually below 1,000,000, for instance 200,000 up to 600,000.

- 5 Useful polymers would ideally exhibit an intrinsic viscosity of below 4 dl/g.

The cationic polymer is suitably introduced into the aqueous suspension in any suitable amount in order to effect flocculation or coagulation of the suspended solids. Usually the dose of polymer is at least 50 grams per tonne (based on dry
10 weight of fermentation liquor). The dose is usually significantly higher, and can be typically up to 5000 grams per tonne. Usually the amount of polymer is added in an amount between 500 and 3000 grams per tonne, especially around 750 to 2000 grams per tonne.

- 15 The treatment system desirably may employ the anionic polymer in conjunction with other flocculant or coagulant additives. A particularly suitable additive to be used as part of the treatment system with the anionic polymer is a siliceous material. The siliceous material may be added simultaneously with the anionic polymer but usually would be added sequentially, especially subsequently to the
20 use of the anionic polymer. The siliceous material may be any of the materials selected from the group consisting of silica based particles, silica microgels, colloidal silica, silica sols, silica gels, polysilicates, aluminosilicates, polyaluminosilicates, borosilicates, polyborosilicates, zeolites or swellable clay.

- 25 This siliceous material may be in the form of an anionic microparticulate material. Alternatively the siliceous material may be a cationic silica. Desirably the siliceous material may be selected from silicas and polysilicates. The silica may be for example any colloidal silica, for instance as described in WO-A-8600100. The polysilicate may be a colloidal silicic acid as described in US-A-
30 4,388,150.

The polysilicates may be prepared by acidifying an aqueous solution of an alkali metal silicate. For instance polysilicic microgels otherwise known as active silica may be prepared by partial acidification of alkali metal silicate to about pH 8-9 by use of mineral acids or acid exchange resins, acid salts and acid gases. It
5 may be desired to age the freshly formed polysilicic acid in order to allow sufficient three dimensional network structure to form. Generally the time of ageing is insufficient for the polysilicic acid to gel. Particularly preferred siliceous material include polyaluminosilicates. The polyaluminosilicates may be for instance aluminated polysilicic acid, made by first forming polysilicic acid
10 microparticles and then post treating with aluminium salts, for instance as described in US-A-5,176,891. Such polyaluminosilicates consist of silicic microparticles with the aluminium located preferentially at the surface.

Alternatively the polyaluminosilicates may be polyparticulate polysilicic
15 microgels of surface area in excess of $1000\text{m}^2/\text{g}$ formed by reacting an alkali metal silicate with acid and water soluble aluminium salts, for instance as described in US-A-5,482,693. Typically the polyaluminosilicates may have a mole ratio of alumina:silica of between 1:10 and 1:1500.

20 The siliceous material may be a colloidal borosilicate, for instance as described in WO-A-9916708. The colloidal borosilicate may be prepared by contacting a dilute aqueous solution of an alkali metal silicate with a cation exchange resin to produce a silicic acid and then forming a heel by mixing together a dilute aqueous solution of an alkali metal borate with an alkali metal hydroxide to form
25 an aqueous solution containing 0.01 to 30 % B_2O_3 , having a pH of from 7 to 10.5.

When the siliceous material is a swellable clay it may for instance be typically a bentonite type clay. The preferred clays are swellable in water and include clays
30 which are naturally water swellable or clays which can be modified, for instance by ion exchange to render them water swellable. Suitable water swellable clays

include but are not limited to clays often referred to as hectorite, smectites, montmorillonites, nontronites, saponite, sauconite, hornblende, attapulgites and sepiolites. Typical anionic swelling clays are described in EP-A-235893 and EP-A-335575.

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The dose of siliceous material would be typically at least 50 grams per tonne (based on dry weight of fermentation liquor). The dose would be usually significantly higher, and can be as much as up to 10,000 grams per tonne or higher. Usually the amount of polymer is added in an amount between 100 and 10 3000 grams per tonne, especially around 500 to 2000 grams per tonne.

In order to ensure that the coagulated or flocculated solids are separated from the liquid medium, the fermentation liquor solid residue is subjected to a mechanical dewatering stage during or subsequent to application of the 15 treatment system. The mechanical dewatering step is ideally selected from at least one of, a centrifuge, a screw press, a filter press, a belt filter press, a horizontal belt filter or preferably a pressure filter.

The aqueous liquid separated from the fermentation liquor solid residues 20 comprises sugars and/or other soluble components and BOD and the aqueous parts are generally free of unwanted suspended solids and desirably recycled into a fermentation process in order to produce a fermentation product.

The dewatered fermentation liquor solid residue comprises lignin and these are 25 generally difficult to dewater. Generally the dewatered fermentation liquor solid residue is subjected to a drying stage and the dried residue may for instance be used as a solid fuel, a nutrient source for further fermentation or a source of chemicals. The process enables the manufacture of the fermentation product to be made more efficiently. Preferably the fermentation product is selected from 30 the group consisting of ethanol, glycerol, acetone, n-butanol, butanediol, isopropanol, butyric acid, methane, citric acid, fumaric acid, lactic acid, propionic

acid, succinic acid, itaconic acid, acetic acid, acetaldehyde, 3-hydroxypropionic acid, glyconic acid and tartaric acid and amino acids such as L-glutamic acid, L-lysine, L-aspartic acid, L-tryptophan, L-arylglycines or salts of any of these acids.

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The following example illustrates the invention.

Example

Various anionic polymers are tested on a post-distillation fermentation liquor to establish filterability or dewatering efficiency. Each anionic polymer is tested by measuring the capillary suction time (CST). CST is based on the suction pressure created by capillaries within absorbent paper. A standard-sized circular area in the centre of a piece of absorbent paper is exposed to the sample, whilst the remaining area of paper is used to absorb the filtrate drawn out by the capillary suction of the paper. The rate at which filtrate spreads outward from the sample, saturating progressively an increasing area of paper, is controlled predominantly by the filterability of the sample. The CST apparatus automatically measures the time for the interface between the wet and dry portions of the paper to travel a given distance. The reading obtained is the CST measured in seconds. The lower the CST the better the filterability. A 10mm diameter sample cell is used. The fermentation liquor sample (8% dry solids) from a fuel ethanol distillery stills bottom is used as a substrate. Polymer is added to the sample. The sample is inverted 8 times and the mixture poured into the CST apparatus. The rate at which free water is drawn outwards from the sample is determined. The faster the rate of dewatering, the lower the CST obtained. The results are shown in Table 1 for the CSTs obtained in comparison with (a) Target CST: from the centrate of a centrifuged sample of the fermentation liquor and (b) Control: water addition alone to the sample rather than polymer. Polymer doses quoted are based on the amount added to the fermentation liquor having a solids content of 8%

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Table 1

Flocculant	Anionic Content (weight %) ¹	Intrinsic Viscosity (dl/g)	CST (seconds)	Polymer Dose (ppm)
Supernatant (Target)			35	
Control (Water)			126	
Polymer 1	20	18	283	30
Polymer 2	30	18	279	30
Polymer 3	40	18	215	30
Polymer 4	40	18	155	30
Polymer 5	50	16	154	15
Polymer 6	52	11	69	30
Polymer 7	55	16	48	30
Polymer 8	70	9	33	120
Polymer 9	100	13	77	240
Polymer 10	100	13	82	120
Polymer 11	100	1	85	120
Carrageenan	Not measured	Not measured	55	180

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¹ polymers are sodium acrylate:acrylamide copolymers except polymers 4, and 7 which are poly 2-acrylamido-2-methylsulphonate:acrylamide copolymers and 11 which is poly 2-acrylamido-2-methylsulphonate